Chapter Six: Water Resource Contamination from Non-point Source Pollution

Several reports that focus on Cape Cod have documented that pollutants derived from septic effluent degrade both ground and surface water resources located within and outside the National Seashore boundary (Persky, 1986; Sobczak and Cambareri, 1995; Valiela et al., 1992; Martin et al., 1992). Several other reports (Valiela et al., 1992; D'Avanzo and Kremer, 1994; Cantor and Knox, 1985) document the far reaching ecological impacts derived from the discharge of contaminated ground water to surface waters. These findings are of great importance to the resource managers at the Cape Cod National Seashore as many of the ponds and estuaries within the National Seashore's boundary are at risk of becoming polluted by increased nutrient loading derived from septic-contaminated ground water discharge (Portnoy, 1994; Portnoy et al., 1998; Martin et al., 1992).

Problem History

On the outer Cape, there is no sewer, and all homes and businesses rely on private septic systems for waste disposal. For almost two decades, various reports have documented increases in nitrate concentrations in the ground water on the outer Cape and have directly linked the elevated levels with increases in housing density and the number of actively used on-site septic systems (Frimpter and Gay, 1979; Persky, 1986; Noss 1989; Goetz et al., 1991; Sobczak and Cambareri, 1995). The Massachusetts Department of Environmental Protection has documented that faulty private septic systems are the largest contributor of pollutants to inland and coastal surface water bodies in the state (Eichner and Cambareri, 1991; Sit, 1995).

Residential and commercial development have been steadily increasing on the outer Cape since the early 1960s. From 1960 to 1975, year round population grew 82 percent, and that population triples during the summer (LeBlanc et al., 1986). Due to the proximity of private water supply wells and septic systems and the nature of the porous sand and gravel aquifer, there is great concern that as population growth on the outer Cape continues and the use of on-site wastewater disposal systems increases, occurrences in cross contamination of clean drinking water supplies will also increase (Sobczak and Cambareri, 1995). In light of increasing development and elevated levels of nitrates, land use planning has become an important issue on the lower Cape. Noss (1989) as well as Harper et al. (1992) examined various land uses that occur in aquifer recharge areas throughout Massachusetts, including Cape Cod. Both reports conclude that residential areas have the greatest impact on nitrate contributions to ground water through the use of on-site septic systems.

The far reaching ecological impacts derived from the discharge of contaminated ground water to surface waters have been well documented (Valiela et al., 1992; D'Avanzo and Kremer, 1994; Cantor and Knox, 1985). However, Hatfield et al. (1994) concluded that in the case of land uses near ground water discharge areas, there is minimal impact on drinking water quality. These findings are of importance to resource managers at the Cape Cod National Seashore as many of the ponds and estuaries within the National Seashore's boundary are at risk of becoming polluted by increased nutrient loading derived from septic contaminated ground water discharge (Portnoy, 1994; Martin et al., 1992). Eutrophication, the increased production of plants, phytoplankton, and macroalgae in surface waters, can result from nutrient loading. Eutrophication not only decreases the natural ecological value of the resource, but also decreases its recreational value to humans (Martin et al., 1992).

Natural background levels of nitrate on the lower Cape are generally less than 1 mg/L (Persky, 1986). The U.S. Environmental Protection Agency maximum contaminant level, safe drinking water guideline for nitrate is 10 mg/L (Table 6.1). Nitrate levels at or above the Massachusetts Department of Environmental Protection and U.S. Environmental Protection Agency safe drinking water guidelines have been linked to methemoglobinemia or blue baby syndrome, a potentially lethal condition which decreases the ability of the blood to transport oxygen in infants (Noake, 1989), and the formation of carcinogenic nitrosamines in adults (Cambareri, 1986). The Cape Cod Commission has set a regional policy planning

Table 6.1. Criteria for selected parameters important to monitoring water quality (adapted from Sobczak and Cambareri, 1995).

Parameter	Criterion	Source of the Criterion
Nitrate	10 mg/L	U.S. Environmental Protection Agency and Massachusetts Department of Environmental Protection Safe Drinking Water Act Guideline
	5mg/L	Cape Cod Commission Regional Policy Plan planning goal, CCPEDC (1991)
Total Dissolved Solids	500 mg/L	U.S. EPA Safe Drinking Water Act Guideline
Fecal Coliform	0 colonies /100ml	Massachusetts Guideline for Drinking Water
Lot Size	0.25 acres 0.50 acres	Legislated by local towns

goal for nitrate concentrations at 5 mg/L. By setting a standard for nitrate below the federal and state standard, Barnstable County is able to manage the problem of contaminated drinking water supplies before it reaches a potentially harmful level (Sobczak and Cambareri, 1995).

Organic, inorganic, and biological pollutants can enter the ground water through septic system leach fields. Biological pollutants are living organisms such as viruses, bacteria, and protozoans which are primarily derived from human fecal matter. Coliform bacteria are the indicator organisms used to detect biological pollutants because their presence may indicate the existence of other pathogenic organisms in ground and surface water resources (Janik, 1987). The state of Massachusetts requires that water samples be checked for the presence of coliform bacteria and that when the coliform bacteria levels exceed zero in the original sample and a check sample, the results must be reported to the Massachusetts Department of Environmental Protection within 48 hours (310 CMR Drinking Water, 1988).

Inorganic pollutants are introduced to the ground water on the outer Cape predominantly through septic system wastewater, landfill leachate, and urban runoff.

Inorganic pollutants are introduced to the ground water on the outer Cape predominantly through septic system wastewater, landfill leachate, and surface runoff (Janik, 1987). The polluted ground water then discharges into ponds and estuaries, which increases the potential for eutrophication of surface waters. The most common inorganic elements in the Cape Cod ground water, derived specifically from septic effluent, are nitrogen and phosphorus. Nitrate which is the form of nitrogen considered to pose the greatest threat to human health, is regulated and monitored in public and private drinking water supplies by the Massachusetts Department of Environmental Protection as outlined in the Massachusetts Drinking Water Regulations (310 CMR 22.00, Drinking Water, 1988).

The addition of phosphorus to pond surface waters via contaminated ground water discharge is a primary management concern ecologically, although it presents no major human health concern. According to Martin et al. (1992), phosphorus introduced to the ponds via septic system runoff has the potential to increase algal production and reduce the natural clarity of the pond waters. Martin et al. (1992) also stated that shoreline septic systems located at several residences, owned by both the National Park Service and private homeowners, are thought to be the primary source of additional phosphorus to some of the lower Cape ponds.

Organic pollutants have the potential to contaminate ground water via septic systems as well. Household cleaners, solvents and any petroleum-based products that are disposed of in sinks or toilets can enter the ground recharge water via the septic system. Household hazardous wastes containing contaminants such as benzene and toluene cannot be treated by on-site septic systems (Noake, 1989). Massachusetts Department of Environmental Protection, as outlined in the Massachusetts Drinking Water Regulations, monitors and regulates the level of organic pollutants in all public water supply systems (310 CMR 22.00, Drinking Water, 1988).

Title 5 (Mass. law 310 CMR 15, Requirements for the disposal of sanitary sewage) regulates the addition of new on-site below-ground septic systems to properties in Massachusetts. Title V also states that when any property is sold, expanded, or altered in its use, an inspection of the existing septic system be performed. The regulation requires that a septic system (i.e., leach field) be located at least 100 feet from surface drinking water supplies and 50 feet from wells, rivers, lakes, ponds, and wetlands. Additionally, a 4-foot unsaturated thickness of soil above high ground water level is also required. This distance is necessary to remove most pathogenic biological pollutants before they reach the ground water (Janik, 1987; Weiskell et al., 1996).

The Challenge

Ensure that a high level of water quality is maintained for both the natural and human environments on the outer Cape while development continues. Find cost efficient methods for alternative wastewater disposal and promote the use of these methods across the outer Cape. Work with surrounding agencies to develop cost effective methods for alternative wastewater disposal.

These distance requirements, however, are based on the distance over which coliform bacteria will be removed from the water. Nitrate and other chemical contaminants are often conserved in subsurface conditions characteristic of the outer Cape and may not be attenuated over distances that are adequate for removal of bacteria (Sobczak and Cambareri, 1995). Since ground water levels can fluctuate seasonally and annually, it is important to locate septic systems sufficiently above the highest possible ground water level (Janik, 1987). Frimpter and Belfit (1992) have created a widely used technique for the siting of septic systems (T. Cambareri, 1996, pers. comm., Cape Cod Commission). The technique allows the high ground water level to be estimated at any location on Cape Cod by comparing the water level taken at any time of the year with a series of index wells of known water level variability (Frimpter and Belfit, 1992).

Impacts of Nutrient Contamination of Ground Water

Nutrient loading, particularly nitrogen contamination, is the principal cause for concern regarding septic wastewaters on the outer Cape (Valiela et al., 1997). Nitrogen is present in the outer Cape ground water in a variety of forms: nitrate, nitrite, ammonium, and gaseous nitrogen. Ammonium is the dominant form in primary wastewaters, but organic nitrogen is more abundant in natural marsh deposits. Nitrate is the primary form in the ground water as well as the primary health issue (Janik, 1987). In the aerobic subsurface conditions of the lower Cape, ammonium in sewage and wastewater effluents quickly becomes oxidized to nitrate over short distances from its source. Nitrate is a negatively charged ion which is repelled by negatively charged soil particles. It is, therefore, conservative, unreactive, and persistent in the ground water (Frimpter and Gay, 1979; P. Veneman, 1996, pers. comm., University of Massachusetts).

All conventional septic systems, even when operating properly under ideal design conditions, will leach nitrogen to the ground water (P. Veneman, 1996, pers. comm., University of Massachusetts.) A minimum lot size of 40,000 square feet is needed to effectively dilute the nitrogen contribution of a single family septic system to concentrations below the Barnstable County planning guideline of 5 mg/L (P. Veneman, 1996, pers. comm., University of Massachusetts). In areas where this minimum lot size is unfeasible, alternative septic technologies, such as recirculating sand filters, peat filters, and the RUCK system have shown potential for increased nitrogen removal. Title V allows for the use of alternative systems in nitrate sensitive areas (P. Veneman, 1996, pers. comm., University of Massachusetts).

In a 1979 survey of ground water quality, Frimpter and Gay (1979) noted that in general the ground water of Cape Cod supplied the residents with good quality drinking water, characteristically low in dissolved solids, and virtually free of toxic heavy metals and organic compounds. Frimpter and Gay (1979) also found the natural pH of the water in general to be mildly acidic, between 6 and 7. The average concentration of nitrate as nitrogen from 84 sites in 1979 was 0.5 mg/L with 90 percent less than 1.3 mg/L. The maximum was 6.3 mg/L from one well near Hyannis. According to Frimpter and Gay (1979), water containing concentrations of nitrate greater than 5 mg/L probably had been impacted by wastewater or fertilizer. While this report indicated that at the time nitrate levels were within safe limits for drinking water, it also stated that the ground water was susceptible to degradation from non-point pollution sources and must be carefully monitored and managed.

A computer generated map of nitrate concentrations was developed by Persky and the U.S. Geological Survey in 1986, seven years after the Frimpter and Gay report. The map Persky developed shows a positive relationship between nitrate concentrations and housing densities on Cape Cod. According to Persky (1986), in five out of nine sample areas, where housing density was greater than one home per acre, nitrate concentrations exceeded 5 mg/L in 25 percent of the wells. In comparison, at one of nine additional sample areas, where housing density was less than one home per acre,

Table 6.2. Aquifer lens water quality data (adapted from Janik, 1987).

Aquifer Lens	Number of Wells Sampled	Percent of Total Number of Wells	Percent > 10 mg/L Nitrate MCL[a]	Percent > 5 mg/L Nitrate[b]
Nauset	668	13%	2%	Not detected
Chequesset	371	12%	4%	10%
Pamet	158	12%	4%	10%

[a]MCL = Maximum Contaminant Level
[b]Cape Cod Commission Planning Goal

nitrate concentrations exceeded 5 mg/L in 25 percent of the wells. The Cape Cod Commission states that today, in many cases, housing lots are 3/4 of an acre or smaller (Sobczak and Cambareri, 1995). A study by Janik (Table 6.2), published in 1987, shows that 10 percent of the wells sampled in the Chequessett lens have nitrate concentrations greater than the regional planning goal of 5 percent.

The seasonal nature of population densities on the lower Cape provides an additional complication to the problem of nutrient loading from septic systems. Postma et al. (1992) found that after 8 to 15 months, the continuous supply of wastewater to a conventional septic system produces a biological clogging mat of reduced permeability at the interface between soils and the leaching facility. The clogging mat then slows the rate at which effluent travels into the soil, promotes an even distribution of effluent throughout the treatment field, and enhances the septic system's ability to filter pollutants. The seasonal use of a septic system prevents the formation of a clogging mat and in turn limits the system's ability to filter pollutants efficiently. In the absence of a clogging mat, septic effluent is unevenly distributed and travels through sandy, porous soils in a concentrated, localized path with little treatment before reaching the ground water (Postma et al., 1992). In situations where the clogging mat may not develop due to coarse soils and/or seasonal use, a pressure dosing type septic system is recommended (P. Veneman, 1996, pers. comm., University of Massachusetts). Pressure dosing systems store effluent in a pumping chamber from which it is pumped at either preset time or volume intervals through a small diameter, slotted PVC pipe. This ensures even effluent distribution throughout the leaching facility, low loading rates, slow unsaturated flow, and enhanced treatment (P. Veneman, 1996, pers. comm., University of Massachusetts).

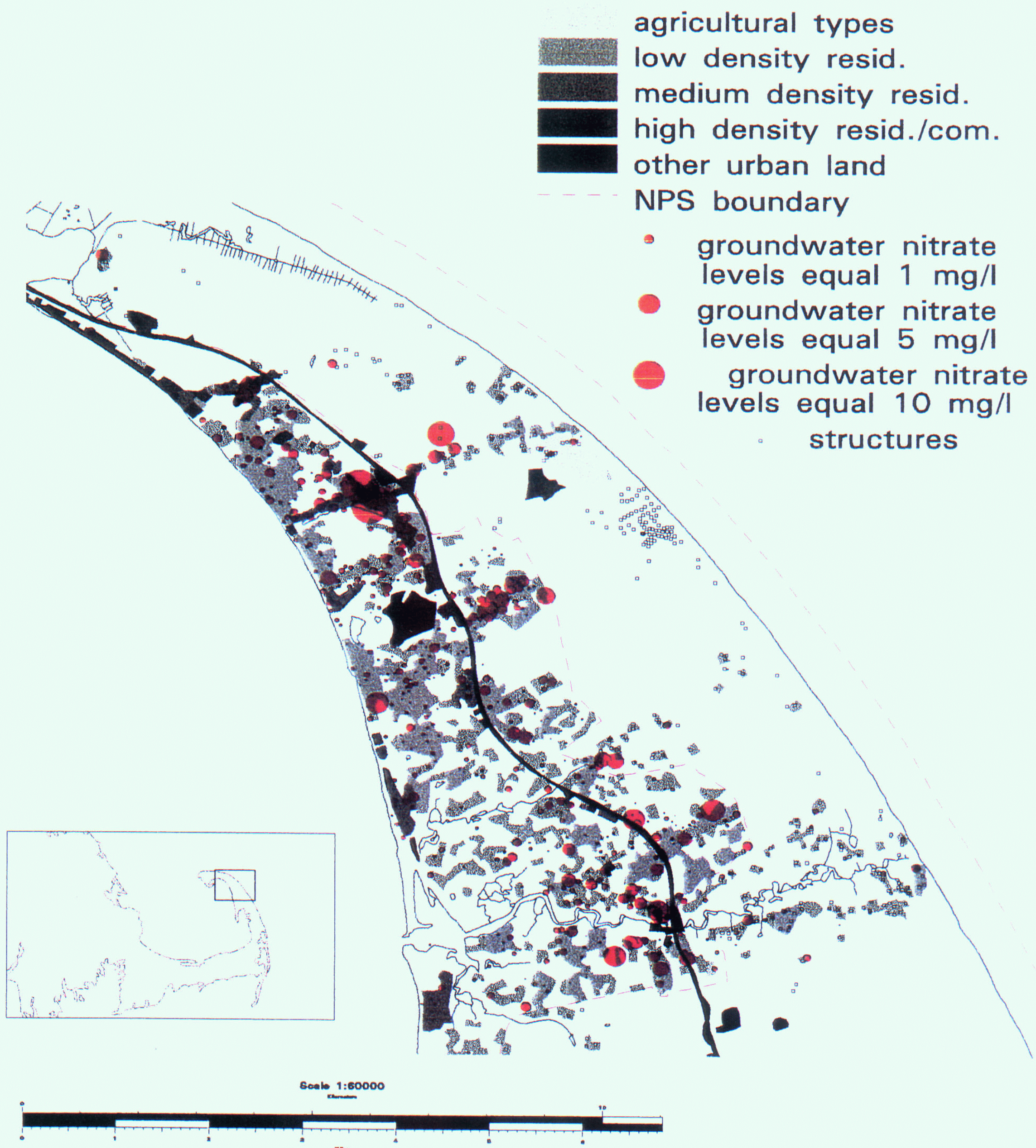
According to a report of the Lower Cape Water Management Task Force (Sobczak and Cambareri, 1996), "analysis of over 7,000 drinking water samples taken between 1980 and 1994 indicate that nitrate in water withdrawn from some private and small volume wells across the lower Cape is approaching or has exceeded public standards for safe drinking water." The report documented that densely populated areas such as Wellfleet Center and the Route 6 corridor in Eastham show the greatest degree of nitrate contamination (Figure 6.1 a-c). Additionally, more than 10 percent of the sampled wells in these areas exceeded the 10 mg/L maximum contaminant level, safe drinking water standard, and many other areas of Wellfleet, Eastham and Truro exceeded the 5 mg/L Barnstable County regional planning goal and approached the drinking water standard. The report also showed that nitrate exceedances have increased for many commercial and residential subregions over a 10 year period from 1984 to 1994. Factors influencing the increasing nitrate levels include: degree of build-out, well depth, well proximity to septic systems, sampling season, local hydrogeology, and local land and water uses (Sobczak and Cambareri, 1995). Densely populated areas, like Wellfleet Center, also using on-site private water wells may not be appropriate for alternative denitrifying septic systems. Although they will reduce nitrate loading to the ground water, other contaminants may continue to enter the ground water via household septics.

Water Resources Management Plan

Figure 6.1a: Nitrate Levels by Parcel - North Truro Quad

Cape Cod National Seashore

Sources: Cape Cod Commission and MassGIS

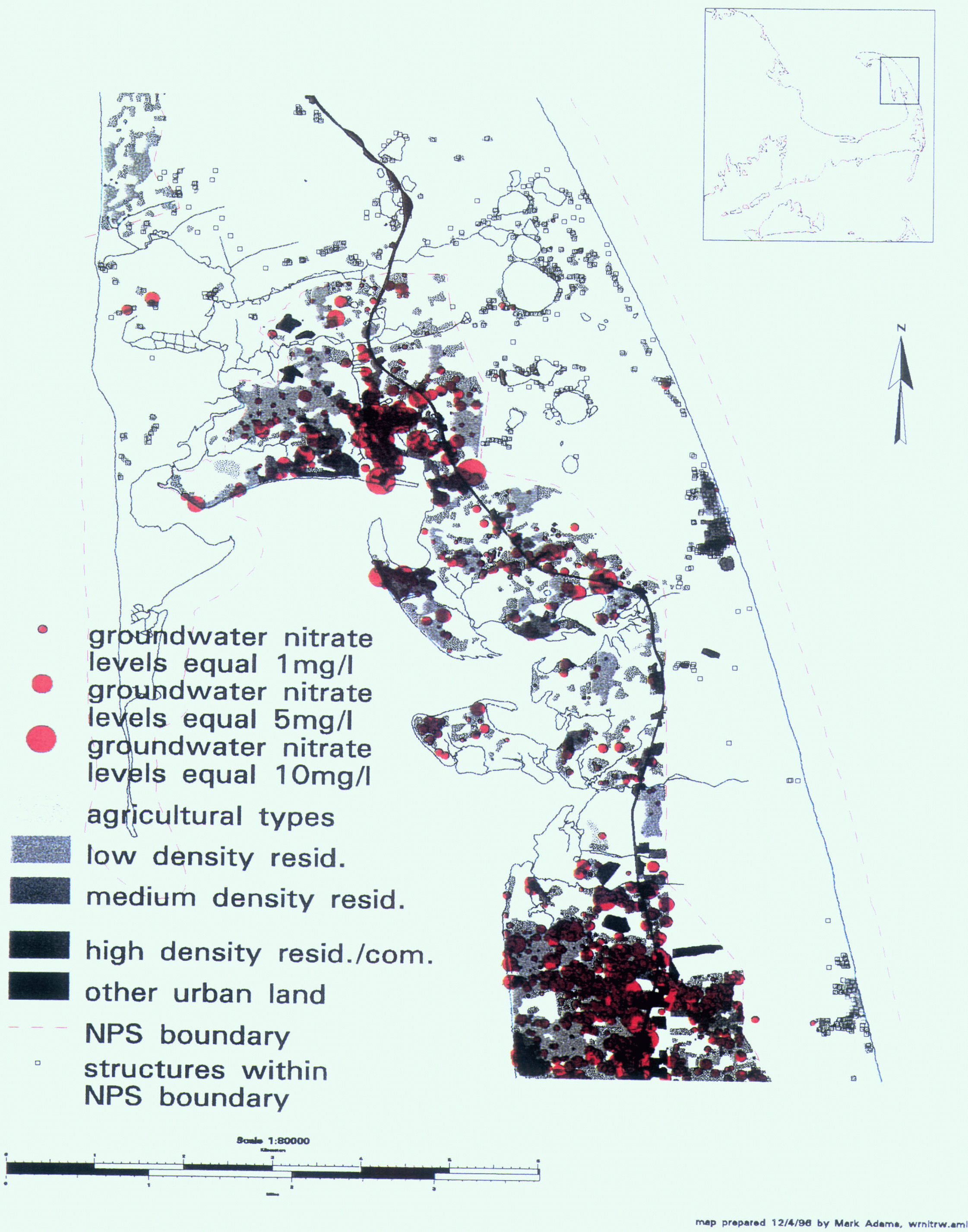


map prepared 12/4/96 by Mark Adams, wrnitrt.aml

Water Resources Management Plan

Figure 6.1b: Nitrate Levels by Parcel - Wellfleet Quad
Cape Cod National Seashore

Sources: Cape Cod Commission and MassGIS



With the loss of nitrate as an indicator of septic contamination, these other contaminants may go undetected (Sobczak and Cambareri, 1996).

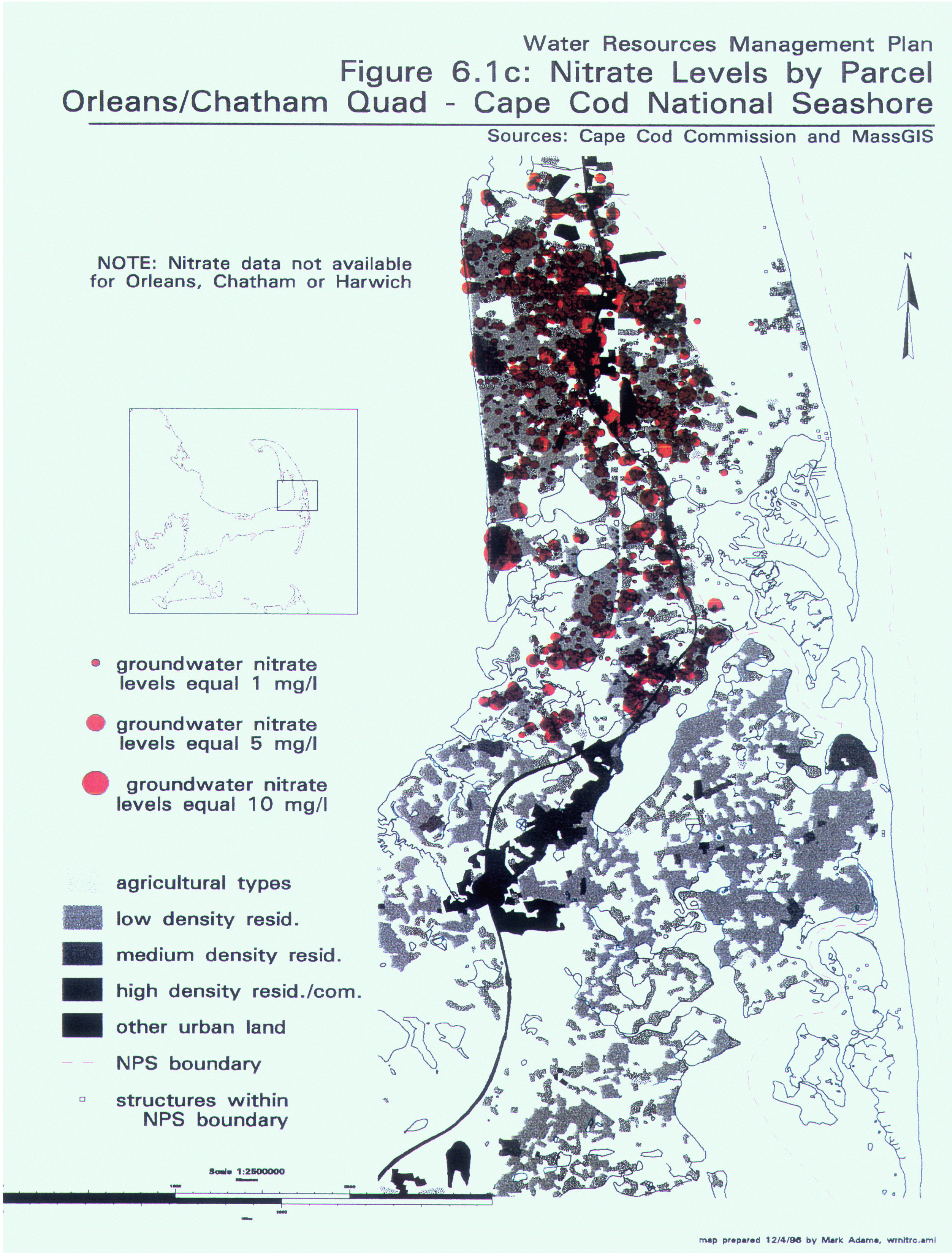
As part of a study on nutrient effects on natural resources (Table 6.3), dissolved inorganic nitrogen was sampled in ground water seeps identified from thermal infrared scans (Portnoy et al., 1998). Samples were taken just as the ground water breaks through the land surface, usually at the low water mark during low tide. Ground water seeping into these areas was contaminated with nitrate-nitrogen likely caused by up-gradient septic systems. Particularly high nitrate was observed in ground water discharge into Mill Pond, which has low-density development with few septic systems. The lots in this residential area have large lawns, however, so leaching of fertilizer could contribute significant amounts of nitrate to the ground water (J. Portnoy, 1996, pers. comm., Cape Cod National Seashore).

A potentially important mechanism for the removal of fixed nitrogen from ground water is denitrification, a microbial respiratory process by which nitrate is converted to gaseous molecular nitrogen. Once in gaseous form, the nitrogen diffuses from the ground water to the atmosphere. In order to work effectively, denitrifying microbes require anaerobic conditions and abundant organic carbon to act as an energy source (Desimone and Howes, 1996). The sandy soils of the lower Cape are generally aerobic and have a very low organic content. The rate of denitrification, therefore, is very low and largely ineffective at reducing ground water nitrate concentrations.

In their 1996 study of a septage plume emanating from an Orleans sewage treatment facility, Desimone and Howes found that an anoxic zone develops in the core of the plume; however, most of the organic content of the

Table 6.3. Dissolved inorganic nitrogen concentrations (mean ± standard error) in ground water seeps discharging into Nauset Marsh (J. Portnoy, 1996, pers. comm., Cape Cod National Seashore).

Location	Month/ Year	Ammonium (mg/L)	Nitrate (mg/L)	Number of Samples
Town Cove	January, 1996	0.2 ± 0.2	1.7 ± 1.7	136
Mill Pond	March, 1996	0.2 ± 0.2	3.7 ± 3.2	20
Fort Hill	March, 1996	0.2 ± 0.2	0.7 ± 0.7	9
Salt Pond Channel	March, 1996	0.1 ± 0.004	0.2 ± 0.1	3
Salt Pond (below visitor's center)	March, 1996	0.2 ± 0.2	1.8 ± 0.8	6


Water Resources Management Plan
Figure 6.1c: Nitrate Levels by Parcel
Orleans/Chatham Quad - Cape Cod National Seashore
Sources: Cape Cod Commission and MassGIS
NOTE: Nitrate data not available for Orleans, Chatham or Harwich
N
groundwater nitrate levels equal 1 mg/l
groundwater nitrate levels equal 5 mg/l
groundwater nitrate levels equal 10 mg/l
agricultural types
low density resid.
medium density resid.
high density resid./com.
other urban land
NPS boundary
structures within NPS boundary
Scale 1:2500000
map prepared 12/4/96 by Mark Adams, wrnitrc.aml

wastewater is stripped in the unsaturated zone before it enters the ground water. They suggest that denitrification could be improved if organic matter could be delivered to the anoxic zone in the plume (Desimone and Howes, 1996).

Impacts of Pond Shoreline Septic Systems

Many of the ponds within the National Seashore boundaries have private homes or inholdings on their shorelines that are accompanied by septic systems (Figure 6.2). Of the 20 kettle ponds located on National Seashore property, only three do not have shoreline residences. The highly permeable nature of the sand and gravel ground water aquifers on the Cape combined with septic system runoff of nutrients, particularly phosphorus, has the potential to cause eutrophication of the ponds. Seasonal residences are now becoming year round residences, increasing wastewater disposal and, potentially, phosphorus loading (Martin et al., 1992). The very low natural background levels of phosphorus in surrounding soils results in low primary production and a high water clarity in the ponds. The addition of human waste from the shoreline septic systems is assumed to be the primary source of phosphorus supporting increased primary production of plants and phytoplankton and cultural eutrophication
(Godfrey et al., 1978; Martin et al., 1992). As mentioned in Chapter 2, the geologic setting of the ponds as well as their depth, area, and other non-point pollution sources influence the ponds' ability to absorb the impacts of additional phosphorus.

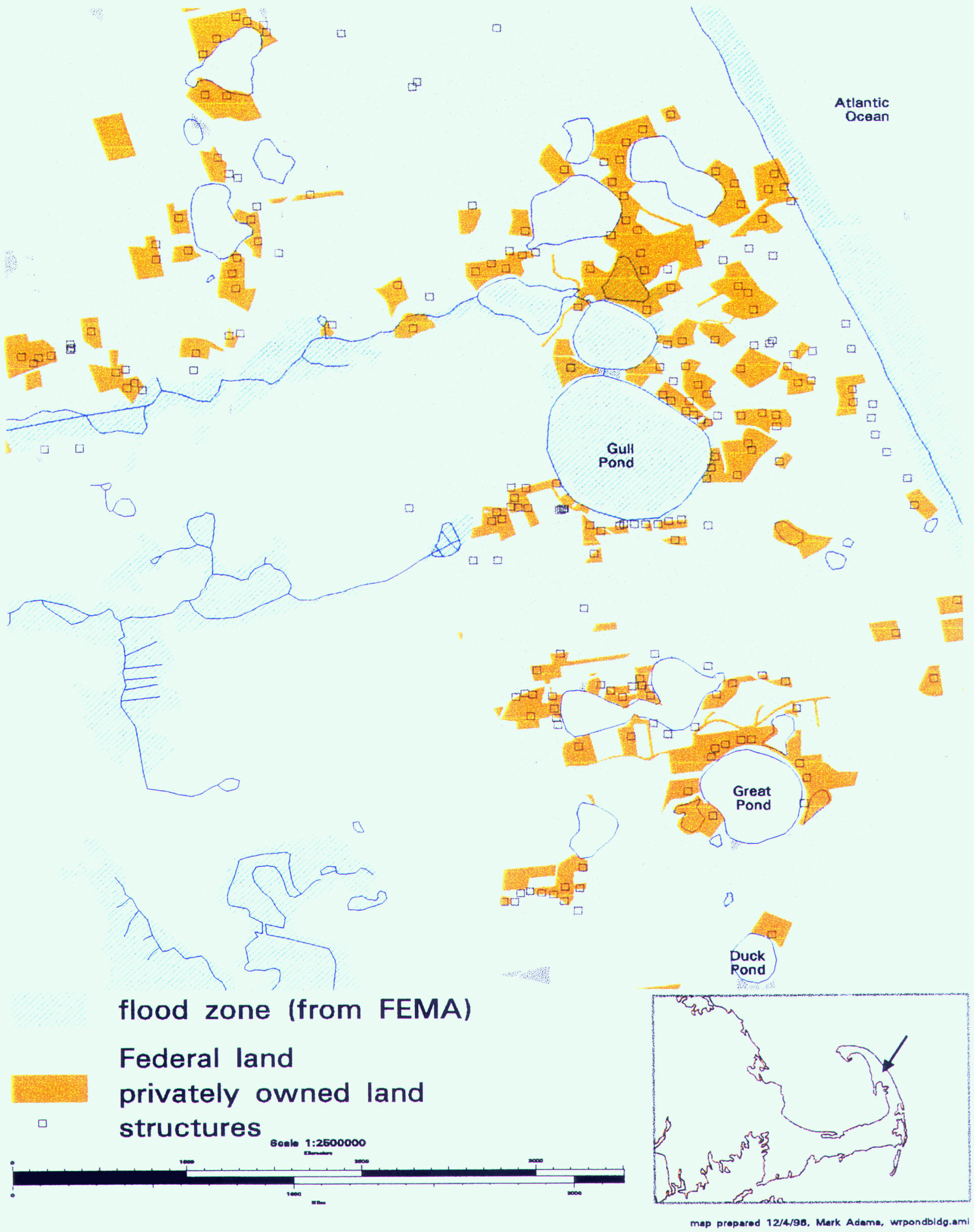
The addition of human waste from shoreline septic systems is assumed to be the primary source of phosphorus and likewise, increased primary production of plants and phytoplankton and cultural eutrophication.

Generally, transport of phosphorus to surface waters is not a major concern since most phosphorus is believed to be retained in the soil (Cantor and Knox, 1985; U.S. Environmental Protection Agency, 1990; Ho and Notodarmojo, 1995). However, sandy soils, like the soils found on Cape Cod, do not retain phosphorus very well. When coarse sandy soils are the only media separating the septic system from the ground water and the septic system is located adjacent to a surface water body, the phosphorus from the septic system moves directly into the ground water and in turn discharges into surface water resources such as ground water fed kettle ponds. Ground water phosphorus concentrations are generally higher under septic systems in sandy soils than in non-sandy soils (Cantor and Knox, 1985). Removal of the phosphorus from the wastewater before it leaves the septic tank is a necessary management measure in this situation (Brandes, 1977). According to the U.S. Environmental Protection Agency, on-site septic systems should not be used if they are located on lakeside lots, near a water body, or in sandy or gravel soils (U.S. Environmental Protection Agency, 1993).

Water Resources Management Plan

Figure 6.2: Shoreline Ownership and Building Density Near Wellfleet Kettle Ponds Cape Cod National Seashore

Sources: ownership from Federal Lands records; structures from 1991 aerial photos



Once in the pond system, most phosphorus is immediately taken up by green plants and algae. During summer, a sharp temperature barrier prevents bottom waters from mixing with the surface waters where oxygen can be replaced by contact with the atmosphere. As a result of the oxygen depletion, a reducing environment is created for the iron in the sediments, and phosphorus is released. With subsequent mixing of the water column, the phosphorus can again become available for algal production. Thus, ponds with higher nutrient loads create an environment where some of past nutrient loads are returned internally from the sediments, exacerbating the effect of external nutrient loads. Hypolimnetic oxygen depletions are common in several National Seashore ponds (Martin et al., 1992).

The National Park Service, recognizing the need to monitor the effects of additional phosphorus on the 20 ponds located within the National Seashore, developed a kettle pond monitoring program in 1992, summarized in Table 6.4. Samples taken for this program have indicated a reduction in pond water clarity at some of the ponds within the National Seashore (C. Farris, 1996, pers. comm., Cape Cod National Seashore). Duck Pond, which has one shoreline residence and a Secchi disk transparency of 36 to 60 feet (11 to 18 meters), has suffered no impacts from additional nutrients (Table 6.5). Gull Pond has 21 shoreline residences. A Secchi disk transparency reading that is typically 13 feet (4 meters), suggests impacts from additional nutrients to the pond's system.

Besides phosphorus, leachate from shoreline septics or runoff from shoreline soils can add biological pollutants to the pond waters. For this reason, staff from the Town of Wellfleet Health Department monitor fecal coliform and total coliform levels during June, July, and August when public use is greatest. Monitoring is done every two weeks in Gull, Long, Great, Duck, and Dyer ponds. Monitoring has occurred for the past 10 years and only twice in that time has a pond been closed for high levels of fecal or total coliform (J. Chatham, 1996, pers. comm., Wellfleet Health Department). According to John Chatham, Director of the Pond Sampling Program, Gull and Long ponds have each been closed once to swimmers, both occurrences over 5 years ago. Chatham noted that increased levels in fecal and total coliform occur predominantly after heavy rainfall events that produce significant runoff. Contrary to popular belief, high water temperature does not appear to be a factor in coliform levels at these five ponds (J. Chatham, pers. comm., Wellfleet Health Department). Gull Pond has 21 shoreline dwellings and Long Pond has 22. Duck, Dyer, and Great ponds each have fewer than 10 shoreline dwellings.

Impacts of Nutrient Loading to Coastal Surface Waters From Septic Systems

Increases in the density of residential and commercial development on the Cape has increased the amount of nutrients that are delivered to rivers and estuaries by ground water discharge. In most cases, the sources of nutrients originate within the watershed rather than outside of it. The most common sources of nitrogen to surface waters are precipitation, fertilizers, and domestic wastewater; however, domestic wastewater delivers significantlymore nitrogen to surface water than either precipitation or fertilizers (Valiela et al., 1997).

Table 6.4. Summary of Kettle Pond Monitoring Program at Cape Cod National Seashore.

I. Annual Spring (April) survey of all 20 ponds.

		Depth Stations	
Field variables	Lab. variables	Field variables	Lab. variables
Temperature	Total phosphorous	1.6 ft. (0.5 m) from surface	1.6 ft (0.5 m) from surface
Conductivity	Nitrate	3.3 ft (1 m) from bottom	
Dissolved oxygen	Phosphate	3.3 ft (1 m) intervals	
Redox potential	Ammonium		
pH	Sulfate		
Light	Chloride		
Secchi depth	Calcium		
	Magnesium		
	Sodium		
	Potassium		
	Chlorophyll *a*		

II. Quarterly (January, April, July, and October) 20 pond survey of pH, alkalinity (surface grab samples) and water level.

III. Summer (May-October) biweekly monitoring of Duck, Dyer, Great (Truro), Great (Wellfleet), Gull, Herring, Long (two basins), Snow, Spectacle and Ryder ponds.

Field variables	Depth Stations
Temperature	1.6 ft (0.5 m)
Conductivity	3.3 ft (1 m) from bottom
Dissolved oxygen	3.3 ft (1 m) intervals
Redox potential	
pH	
Light	
Secchi depth	

IV. Annual August survey of all 20 ponds.

		Depth Stations	
Field variables	Lab. variables	Field variables	Lab. variables
Temperature	Total phosphorus	1.6 ft (0.5 m) from surface	1.6 ft (0.5 m) from surface
Conductivity	Nitrate	3.3 ft (1 m) from bottom	
Dissolved oxygen	Phosphate	3.3 ft (1 m) intervals	
Redox potential	Ammonium		
pH			
Chlorophyll *a*			
Light			
Secchi depth			

Table 6.5. Depths and measures of typical summer (1996) productivity in five Cape Cod kettle ponds.

Pond	Depth (m)	Secchi (m)	Total Phosphorus (ppb)	Chl a (mg m^{-3})
Duck	18	11	7-8	2-3
Gull	18	4	10-17	2-3
Ryder	11	8	16-21	3-5
Great (Truro)	10	6	9-18	6-7
Herring	4	3	60-70	14-17

Unlike fresh water, where phosphorus is generally the limiting nutrient, nitrogen is generally the limiting nutrient in estuaries.

Ground water is the primary mechanism by which surface waters receive nutrients from septics (Valiela et al., 1992; 1997). Lowland resources, such as streams and estuaries, receive ground water flow (Sobczak and Cambareri, 1995) and because of this connection, estuaries, rivers, and ponds are susceptible to contamination from ground water discharge that contains organic, inorganic and biological pollutants. A preliminary analysis of Town Cove, Orleans, using aerial thermal sensing, displays the extent of ground water inflow into the estuary (Figure 6.3). Ground water discharge containing high concentrations of nutrients, predominantly from septic leachate, has led to the eutrophication of shallow coastal ecosystems in the Waquoit Bay watershed, Cape Cod. Valiela et al. (1992) attribute the increase of nutrients in surface waters, the greater primary production of phytoplankton, and increased macroalgal biomass to the growth in population and housing density on the Cape and the subsequent increase in nitrogen leaching from septic systems. Both Valiela et al. (1992) and D'Avanzo and Kramer (1994) note that increased nutrient loading to surface waters in Waquoit Bay has also led to an increase in red and green nuisance algae and a decrease in eelgrass beds, reduced oxygen levels, and significant decreases in shellfish and finfish populations.

Unlike fresh water, where phosphorus is generally the limiting nutrient, nitrogen is generally the limiting nutrient in estuaries.

Tidal flushing is the primary mechanism for removal of nutrients, specifically nitrogen from coastal surface waters (Valiela et al., 1978; Valiela and Teal, 1979). In the absence

Figure 6.3. Discharge of cold (dark) ground water into relatively warm estuarine waters of Town Cove, Orleans, August 1994 (Aero-Marine Surveys, Inc., Groton, CT).

of tidal flushing, nutrients introduced to coastal water bodies can remain in the system, increase algal production, and promote eutrophication.

An example of this is Pilgrim Lake, a shallow coastal lagoon located in North Truro. Pilgrim Lake has been closed off from tidal influences since about 1860 and is experiencing advanced stages of eutrophication due to the accumulation of nutrients, particularly phosphorus and nitrogen (Emery and Redfield, 1969; Mozgala, 1974; Applebaum and Brennickmeyer, 1988).

Recently, the National Park Service completed a three-year study of nitrogen loading from ground water to Nauset Marsh. There is concern about eutrophication of the surface waters (Portnoy, 1994; Portnoy et al., 1998; Nowicki et al., in press).

The purpose of this study is to:

1. describe patterns of ground water discharge and nitrogen contamination;
2. describe the extent of denitrification; and,
3. produce an estimate of nitrogen loading from estuaries to ground water.

The first year of study on the outer Cape surveyed ground water nutrient concentrations at 14 sites around Nauset Marsh. Ground water nitrogen levels were elevated above background levels at all shorelines surveyed except Salt Pond Bay; nitrate concentrations were directly related to the intensity of upgradient development. Along the developed shore in Orleans, nitrate concentrations averaged 2.8 mg/L, almost 40 times unpolluted background concentrations (Portnoy, 1994).

Management Steps: Non-point Contamination from Wastewater Disposal
400 Days to 5 Years

Committee
Examine current zoning as it relates to water resources. Evaluate the optimal size of cluster developments that minimize ecological impacts of wastewater treatment. Examine the current use of fertilizers.

Education
Develop a segment in the newsletter that deals with septic and alternative systems. Incorporate information about proper wastewater disposal into school and public education programs.

Data Management
Collect information related to nutrient loading in ponds, estuaries, and ground water. Place information in a format that allows for easy comparative analysis.

Research
Continue to monitor nutrient loading into the ponds. Study the potential impacts of fertilizer use on drinking water supplies and ecological resources.

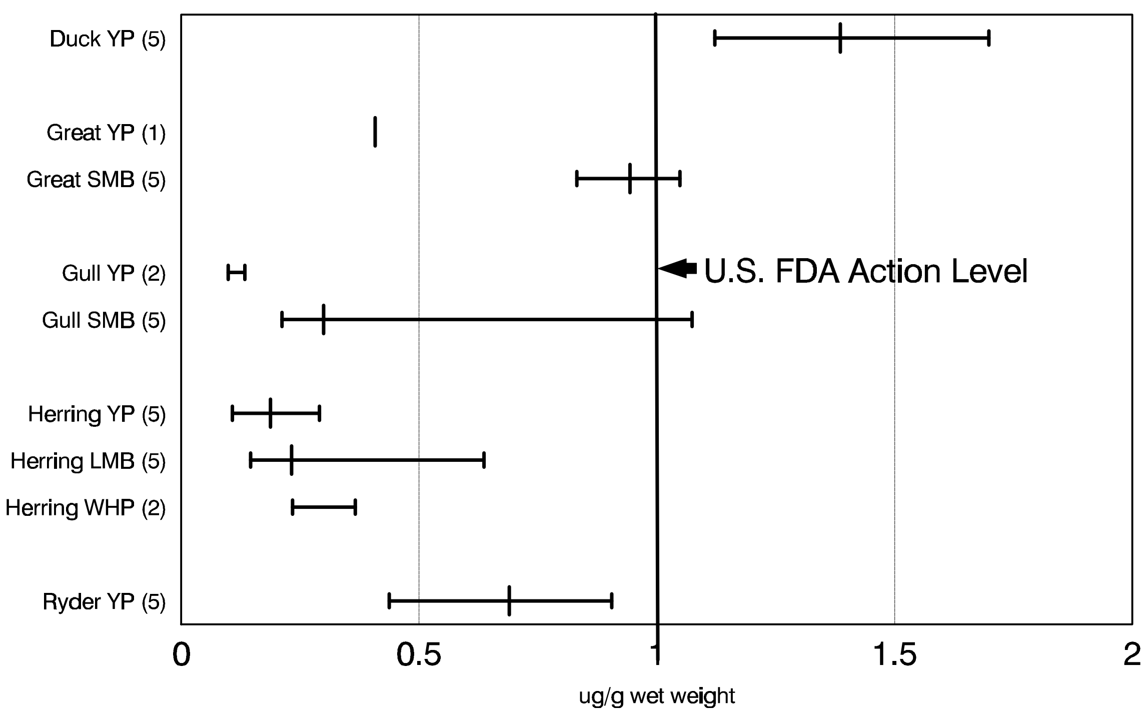
CONTRIBUTING ISSUES

Atmospheric Deposition of Mercury

Atmospheric deposition is implicated as the major source of mercury in the kettle ponds of the National Seashore (Haines, 1996). Yellow perch, a favorite with fishermen, is known to accumulate mercury in its tissues. At the National Seashore's three most acidic ponds [Duck, Dyer and Great (Wellfleet)], yellow perch have exhibited necrotic lesions on the head and gill covers, a syndrome known as "hole in the head" disease (Winkler, 1994). The Biological Resources Division of the U.S. Geological Survey is currently engaged in a monitoring program that evaluates mercury contamination in five kettle ponds on the National Seashore as well as at Acadia National Park. A recent progress report shows that yellow perch in all five of the ponds studied have mercury accumulations (Haines, 1996; Figure 6.4). These preliminary findings suggest that atmospheric deposition of mercury is a threat to the National Seashore's surface waters.

A similar study in Massachusetts (Massachusetts Department of Environmental Protection, 1997b) found bioaccumulations of mercury in largemouth bass and yellow perch but less so in brown bullhead. The study did not include any lakes on Cape Cod. However, there was a strong correlation between conditions indicative of acid deposition impacts, such as low pH and calcium and

Figure 6.4. Median and Range of Mercury Concentrations in Fish Fillets from Five Kettle Ponds on Cape Cod National Seashore (from Haines, 1996; Standards from NESCAUM, 1998). Great = Great Pond (Truro).



SMB = Smallmouth Bass; YP = Yellow Perch; LMB = Largemouth Bass; WHP = White Perch.
Sample size in ( )

higher mercury concentrations in predaceous fish tissue. Low pH and calcium are typical chemical characteristics of nearly all Cape ponds (Godfrey et al., 1996).

Lakes, ponds, and rivers with high acidity easily transform the inorganic mercury from the atmosphere's pollution to more toxic organic forms of mercury. Additionally, bioaccumulation of mercury in the food chain is increased with high levels of acidity. Since many of the incinerators in Massachusetts are not properly equipped to remove mercury from air emissions, mercury is a prevalent air pollution problem in the state. Incinerators burn over 11,000 tons of trash every day and emit 19 tons of mercury per year in Massachusetts.

Acid Rain

Acid deposition is relatively high on Cape Cod. Acid deposition is produced when the atmosphere is contaminated with nitrates and sulfates. Sulfate in precipitation on the Cape declined by about 16 percent from the late 1980s to the mid-1990s; however, the volume-weighted average pH of the precipitation did not change significantly (Table 6.6). Some ponds and streams on the lower Cape have been monitored quarterly from 1983 to 1994 by the Acid Rain Monitoring Project (ARM Project) of the University of Massachusetts, Amherst (Godfrey et al., 1996) and Long Pond was monitored by the Eastern Lakes Survey (U.S. Environmental Protection Agency, 1986). A comparison of these two surveys for Long Pond is shown in Table 6.7. Generally the ponds on the Cape are very low in both pH and alkalinity (Godfrey et al., 1996; Mattson et al., 1992) and would be expected to be very sensitive to changes in acidic inputs. Although there appears to be a general trend toward increasing pH and alkalinity in Massachusetts (Godfrey et al., 1996), this trend is not apparent on Cape Cod.

Table 6.6.
National Atmospheric Deposition Program data (NADP/NIN Coordinating Office, 1981 to 1996), for sulfate and lab pH for precipitation at Truro, Mass. Data from *nadp.nrel.colostate.edu/NADP*. Variability not reported.

Year	Lab pH	Sulfate (mg/l)
1981	4.49	2.00
1982	4.41	2.14
1983	4.65	1.62
1984	4.63	1.47
1985	4.41	2.15
1986	4.42	1.88
1987	4.51	1.67
1988	4.39	2.18
1989	4.49	1.85
1990	4.54	1.62
1991	4.41	1.98
1992	4.54	1.54
1993	4.63	1.50
1994	4.53	1.44
1995	4.49	1.51
1996	4.61	1.37

Eleven of the ponds and two streams have sufficient data to analyze for trends in acid/base chemistry from 1983 to 1994 (Table 6.8). All of the ponds and both streams have very low, or even negative alkalinities and low pH. The results show that Northeast Pond is increasing in alkalinity, Kinnacum Pond is decreasing in alkalinity and the remaining nine ponds are not significantly changing in alkalinity. Both of the streams with available data have significant trends in adjusted alkalinity; Herring River is increasing in alkalinity while Silver Spring Brook is decreasing in alkalinity (Mattson et al., 1997; Godfrey et al., 1996). Thus, while the ponds are fairly acidic there appears to be little change in the acidity status over the past 10 years.

According to several reports, temporary ponds in the United States are not only critical habitats for amphibians but also freshwater bodies extremely sensitive to atmospheric deposition of acids (Portnoy, 1990; Jackson and Griffin, 1991).

In light of these characteristics, many studies have attempted to find a correlation between the breeding success of amphibians and acidification of breeding ponds. Focusing on the relationship between water chemistry and the breeding success of spotted salamanders in temporary woodland ponds on the lower Cape, Portnoy (1990) observed that successful embryonic development and hatching occurred at pHs as low as 4.5. He concluded that Cape mole salamanders have been reproducing successfully at low pH levels for hundreds, perhaps thousands of years given the lower Cape soils, vegetation, and long history of acidic environments. Jackson and Griffin (1991) explored differences in acid tolerance within mole salamanders. Realizing a highly variable intra-species sensitivity to acidity, Jackson and Griffin concluded that locally, "habitat loss is probably a more immediate threat to salamander populations than acid precipitation."

Current Monitoring

National Atmospheric Deposition Program: Data Collection and Monitoring (NADP)

NADP consists of weekly precipitation samples collected to monitor precipitation chemistry. A monitoring site located within the Cape Cod National Seashore in Truro provides data on pH, calcium, magnesium, potassium, sodium, nitrate, chlorine, ammonium, sulfate, and hydrogen.

Table 6.7. Comparison of data for Long Pond, Wellfleet (PALSARIS Code #96179) resulting from the U.S. Environmental Protection Agency Eastern Lakes Survey (STORET) and the Acid Rain Monitoring Project.

Parameter	STORET from U.S. EPA Eastern Lake Survey (11/6/84, one sample only)	Acid Rain Monitoring Project Average from 1983-1993 (Number of samples)	Parameter	STORET from U.S. EPA Eastern Lake Survey (11/6/84, one sample only)	Acid Rain Monitoring Project Average from 1983-1993 (Number of samples)
Temperature °c	13.2		**Mg (mg/l)**	1.4	1.41 (29)
Transparency (m)	7.9		**Na (mg/l)**	11.83	11.71 (29)
Color (PCU)	5	4.00 (27)	**K (mg/l)**	0.84	0.78 (30)
Conductance (umhos/cm)	97		**Si (mg/l as SiO_2)**	0.04	0.04 (28)
SO4-S (mg/l)	7.32	7.54 (30)	**Cl (mg/l)**	22.0	20.67 (30)
pH	4.7	4.64 (43)	**Fl (mg/l)**	0.01	
ANC (ueq/l)	-18.1	-19.6 (43)	**Mn (ug/l)**	55.5	50 (29)
Total P (ug/l)	5.7	3.9 (1)	**Al (ug/l)**	51	80 (30)
DIC (mg/l)	0.6		**NO3-N (mg/l)**	0.07	0.01 (30)
DOC (mg/l)	0.3		**Fe (ug/l)**	31	50 (29)
Ca (mg/l)	1.1	1.20 (30)	**Turbidity (NTUs)**	0.4	

Sampling depth = 1 meter for U.S. EPA samples and 2/3 meter for ARM samples.

Table 6.8. Surface Water acid/base trends, 1983-1994, on Lower Cape Cod. Average pH, average alkalinity, trend in alkalinity (adjusted to remove the effect of yearly variation in precipitation and runoff), and significance level of trend from (Godfrey et al., 1997). Alkalinity and trends in units of calcium carbonate mg/l and mg/l/yr., respectively.

Name	Town	Ave. pH	Ave. Alk.	Trend	Significance Level
Ponds					
Northeast	Wellfleet	4.86	- 0.44	+0.13	<0.05
Kinnacum	Wellfleet	4.47	- 1.83	- 0.14	<0.05
Dyer	Wellfleet	4.81	- 0.64	- 0.06	NS
Great	Wellfleet	4.70	- 0.83	+0.04	NS
Gull	Wellfleet	6.63	+3.18	+0.06	NS
Higgins	Wellfleet	6.51	+3.30	+0.13	NS
Horseleech	Truro	5.79	+0.67	- 0.04	NS
Round	Truro	4.81	- 0.56	+0.02	NS
Slough	Truro	4.78	- 0.66	+0.02	NS
Spectacle	Wellfleet	5.01	- 0.11	+0.01	NS
Williams	Wellfleet	5.92	+1.69	+0.02	NS
Streams					
Herring River	Wellfleet	6.08	+6.49	+0.25	<0.05
Silver Spring Brook	Wellfleet	6.54	+9.14	- 0.25	<0.05

NS = not significant at the 0.05 level